T962 LAR TPC DEWAR CACULATIONS

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April 23, 2007

(1.0) Introduction

This document presents calculations used for the T962 LAR TPC preliminary Minos Hall ODH analysis. A number of approximations and estimates were made in these calculations that will have to be revised for the final safety documentation. The intent here was to have calculations accurate enough to show it is feasible that the Minos Hall can be made ODH Class 0.

From Airco Industrial Gases Data Handbook (AGG 1077C), the following data was acquired. Listed are the densities at standard conditions (70 F and 1 ATM) of helium. nitrogen and air. Also there is the density of Liquid nitrogen at 1 ATM and the conversion of gallons of liquid nitrogen to cubic feet of nitrogen gas at standard conditions.

```
RhoStdAir  =  0.07493**(lb/ft^3)      (density of air at standard conditions)
RhoStdAr  =  0.1034**(lb/ft^3)      (density of argon at standard conditions)
RhoLAr  =  1.3936**(lb/L)      (density of liquid argon at 1 atm)
```

density of water

```
rhoH2O  =  62.4**(lb/ft^3)
```

(2.0) Size Dewar Burst Disc For Fire

(2.1) Surface Area

The surface area of the argon dewar is needed to determine the Dimensions of argon dewar inner vessel are:

```
InnerOD  =  30**in      (outside diameter of inner vessel)
InnerL  =  50.63**in      (overall length of inner vessel)
```

From the available drawing, the neck is 24 in pipe. I assume the neck will contain baffles to reduce radiation from the top plate to the the liquid argon.

```
NeckOD  =  24**in      (outside diameter of 24  pipe)
NeckL  =  16**in      (approximate length of vacuum insulated portion of neck)
MAWP  =  30**psig      ( dewar maximum allowable pressure)
```

Calculate the mean area of insulation. Assume the insulation is 1 in thick. This is quick and dirty. The size of the neck is huge compared to the main vessel. Assume an insulation thickness of 1 inch covering the outside of the inner vessel. Calculate the area of the surface running through the middle of the insulation.

```
InsT  =  1**in
CylArea  =  Pi()*(InnerOD+InsT)*(InnerL+InsT)+2*Pi()*(InnerOD+InsT)^2/4
CylArea  =  6537.7485598999**(in^2)
NeckArea  =  Pi()*(NeckOD+InsT)*NeckL
NeckArea  =  1256.6370614359**(in^2)
InsArea  =  CylArea+NeckArea
InsArea  =  7794.3856213358**(in^2)
InsArea  =  Convert(ToFt)InsArea
InsArea  =  54.1276775795**(ft^2)
```

(2.2) Fire Condition

Find the mean thermal conductivity of air between 1200F and Saturation temperature from CGA S-1.3 p32, Table 3.

```
khotair  =  0.024573**(BTU/(hr*ft*F))
```

Overall heat transfer coefficient

```
U  =  khotair/InsT
U  =  0.024573**(BTU/(hr*ft*F*in))
U  =  Convert(ToFt)U
U  =  0.2948760001**(BTU/(hr*ft^2*F))
```

Calculate the required relief valve capacity as per CGA S-1.3, section 5.3.3. To be consistent with the CGA method of calculations, make A a non-dimensional variable equaling the number of square feet of surface.

```
A  =  InsArea/1**ft^2
A  =  54.1276775795
Ff  =  1.0
Gi  =  10.2**((ft^3*hr*ft^2*F)/(min*BTU))
Qa  =  Ff*Gi*U*A^0.82
Qa  =  79.3676463193**(ft^3/min)
```

As per CGA 5.3 (c), reduce the required flow capacity Qa to 30% of its value because of the fire protection sprinkler system in the cavern. Qa is the stamped capacity on a relief device in standard cubic feet of air.

```
Qa  =  0.3*Qa
Qa  =  23.8102938958**(ft^3/min)
```

(2.3) Burst Disc Size

Determine required size of burst disc as ASME Boiler Pressure Vessel Code, Section VIII Div I, Appendix 11.

```
Wa  =  Qa*RhoStdAir      (mass flow rate of air)
Wa  =  1.7841053216**(lb/min)
Wa  =  Convert(ToHr)Wa
Wa  =  107.0463197249**(lb/hr)
Mair  =  28.97      (molecular weight)
T  =  520**R      (temperature)
P  =  14.7**psia+1.1*MAWP      (inlet abso;ute pressure, 10% over MAWP)
P  =  47.6999999999**psia
C  =  356**((R^0.5*lb)/(hr*in^2*psia))
Kv  =  0.62
```

NOTE: is Kv = 0.61 or 0,62??

Find Ab, area of burst disc.

```
Ab  =  Wa/(C*Kv*P)*(T/Mair)^0.5
Ab  =  0.0430763699**(in^2)
```

Find the diameter

```
db  =  4*Ab^0.5/Pi()
db  =  0.2642589273**in
```

A 1/2 inch burst disc is required for the fire condition for the fire condition for this vessel.

(2.4) Actual Required Mass Flow Rate Of Argon

Find out what the mass flow rate of argon that will be going through the burst disc for the fire condition. Determine the amount of helium that would flow through the burst disc. Note: what will Tar really be?

```
Tar  =  100**K
Tar  =  Tar*(9/5)**(R/K)
Tar  =  180.**R
Mar  =  39.944      (molecular weight of argon)
War  =  Kv*Ab*C*P*(Mar/Tar)^0.5
War  =  213.6430104228**(lb/hr)
```

(2.5) Pressure Drop in Exhaust Line

Pressure drop through vent line

Inputs

```
od  =  1.900**in      (outside diameter 1 1/2" pipe)
wall  =  0.065**in      (wall thickness 1 1/2" sch 5 pipe)
Le  =  200**ft      (length)
Tf  =  (460+1200)**R
Tf  =  1660**R
```

Viscosity is at 1 atm 400K.

```
mu  =  289.2e-6**(gm/(cm*s))      (viscosity)
mu  =  Convert({ToLb,ToFt})mu
mu  =  0.194333415e-4**(lb/(ft*s))
w  =  213.6430104228**(lb/hr)      (mass flow rate)
```

Density

```
pin  =  1.5**atm      (inlet pressure)
pout  =  1.0**atm      (outlet pressure)
rhoin  =  RhoStdAr*pin/1**atm*520**R/Tf      (inlet density)
rhoin  =  0.0485855421**(lb/ft^3)
rhoout  =  RhoStdAr*pout/1**atm*520**R/Tf      (outlet density)
rhoout  =  0.0323903614**(lb/ft^3)
rhoave  =  (rhoin+rhoout)/2      (average density)
rhoave  =  0.0404879518**(lb/ft^3)
rhoave  =  Convert({ToFt,ToLb})rhoave
rhoave  =  0.0404879518**(lb/ft^3)
```

Velocity

```
id  =  od-2*wall      (inside diameter)
id  =  1.77**in
a  =  2.4605739061**(in^2)      (flow area)
v  =  2144.502058687**(ft^3/(hr*in^2))      (velocity)
v  =  Convert({ToFt,ToSec})v
v  =  85.7800828956**(ft/s)
```

Friction Factor

```
Re  =  id*v*rhoave/mu      (Reynolds number)
Re  =  0.3163283038e6**(in/ft)
Re  =  Convert(ToFt)Re
Re  =  0.0263606919e6
epsilon  =  0.00015**ft      (pipe roughness)
f  =  FrictionFactor3(Re,epsilon,id)      (friction factor)
f  =  0.0266692192
```

K factors

```
Kin  =  0.5
Kout  =  1.0
Kl  =  f*Le/id
Kl  =  3.0134710984**(ft/in)
Kl  =  Convert(ToFt)Kl
Kl  =  36.161653196
Ktotal  =  Kin+Kl+Kout      (total K factor)
Ktotal  =  37.661653196

dp  =  Ktotal*rhoave*v^2/(2*gc)      (pressure drop)
dp  =  174.3665028525**(lbf/ft^2)
dp  =  Convert(ToIn)dp
dp  =  1.210878492**(lbf/in^2)
```

(3.0) Loss of Vacuum

(3.1) Find Required Relief Capacity in Free Air

Follow the CGA code. First find the saturation temperature of argon at a pressure equal to 110% of MAWP.

```
P110  =  1.1*MAWP+14.7**psia
P110  =  47.6999999999**psia
Convert(ToBar)P110  =  3.288799089**bar
T110  =  100.056**K      (saturation temperature)
Tinsmean  =  (T110+300**K)/2      (mean temperature of insulation)
Tinsmean  =  200.0279999999**K
kamean  =  18.10e-3**(W/(m*K))
Convert({ToBTUperHr,ToFt,ToF})kamean  =  0.1045798556e-1**(BTU/(hr*ft*F))
U  =  kamean/InsT
U  =  0.181e-1**(W/(m*K*in))
U  =  Convert({ToBTUperHr,ToFt,ToF})U
U  =  0.1254958268**(BTU/(hr*ft^2*F))
```

For now keep the same U. Its at a different tremperature

NOTE: Find right k and U

```
T110  =  T110*(9/5)**(R/K)      (convert units of temperature)
T110  =  180.1008**R
Gi  =  10.2**((ft^3*hr*ft^2*F)/(min*BTU))
A  =  54.1276775795
Ff  =  1.0
U  =  0.1254958268**(BTU/(hr*ft^2*F))
Qav  =  (590**R-T110)*Ff*Gi*U*A/(4*(1660**R-T110))
Qav  =  4.797707793**(ft^3/min)
```

(3.2) Find Required Orifice Area

Follow ASME section VII Div 1, Appendix 11

```
Wav  =  Qav*RhoStdAir
Wav  =  0.3594922449**(lb/min)
Wav  =  Convert(ToHr)Wav
Wav  =  21.5695347822**(lb/hr)
Mair  =  28.97
T  =  520**R
P  =  14.7**psia+1.1*MAWP
P  =  47.6999999999**psia
C  =  356**((R^0.5*lb)/(hr*in^2*psia))
Kv  =  0.62
Av  =  Wav/(C*Kv*P)*(T/Mair)^0.5
Av  =  0.8679768375e-2**(in^2)
```

(3.3)

Determine the amount of argon that would flow through the burst disc.

```
Kv  =  0.62
C  =  377**((R^0.5*lb)/(hr*in^2*psia))
P  =  47.6999999999**psia
Tar  =  100**K
Mar  =  39.944
Tar  =  Tar*(9/5)**(R/K)
Tar  =  180.**R
Wvar  =  Kv*Av*C*P*(Mar/Tar)^0.5
Wvar  =  45.5878466429**(lb/hr)
RRv  =  Wvar/RhoStdAr
RRv  =  440.8882654055**(ft^3/hr)
RRv  =  Convert(ToMin)RRv
RRv  =  7.3481377567**(ft^3/min)
```

(4.0) Vacuum Relief

(4.1) Required Discharge Area.

Use the quaint formula from CGA S-1.3, section 4.42. Find the water volume (quantity of water it can hold.

```
watervolume  =  InnerL*Pi()*InnerOD^2/4+NeckL*Pi()*NeckOD^2/4      (internal volume
watervolume  =  0.4302646758e5**(in^3)
watervolume  =  Convert(ToFt)watervolume
watervolume  =  24.8995759894**(ft^3)
```

The volume of the cathid plates can be deducted.

```
rda  =  0.00024**(in^2/lb)*rhoH2O*watervolume      (required discharge area)
rda  =  0.37289605**(in^2)
```

(4.2) Required Flow Rate

To find the required flow rate assume the flow is saturated vapor with 1 psig internal pressure. Treat the discharge area as a short pipe. Assume incompressible flow.

density of saturated argon at 1 atm. AIRCO Industrial Gases Data Book

```
rho  =  0.35976**(lb/ft^3)      (inlet density)
a  =  0.37289605**(in^2)      (flow area)
dp  =  1**(lbf/in^2)      (pressure drop)
dp  =  1**(lbf/in^2)
```

input K factors

```
Kin  =  0.5
Kout  =  1.0
Ktotal  =  Kin+Kout      (total K factor)
Ktotal  =  1.5
```

calculate velocity

```
v  =  ((dp*2*gc)/(Ktotal*rho))^0.5      (velocity)
v  =  10.9198195008**(ft^2./(in*s))
v  =  Convert(ToFt)v
v  =  131.037834062**(ft/s)
```

outputs

```
w  =  a*v*rho      (mass flow)
w  =  17.5791294229**((in^2*lb)/(s*ft^2))
```

Convert units

```
w  =  Convert({ToFt,ToHr})w
w  =  439.4783558168**(lb/hr)
```

Find volumetric flow at standard conditions

```
Rvj  =  w/rho      (volumetric flow at standard conditions)
Rvj  =  1221.5876023372**(ft^3/hr)

Rvj  =  Convert(ToMin)Rvj
Rvj  =  20.3597933722**(ft^3/min)
```

(5.0) Dewar Boil Off

Assume the argon dewar is at 3 bar and full of saturated liquid. Assume the dewar is suddenly open to atmosphere; either a large valve is opened or a pipe is severed in two pieces. Ignore heat load on the dewar.

(5.1) Liquid and Vapor Properties

At 1 bar.

```
uL1  =  73.677**(J/gm)      (internal energy, sat liquid at 1 bar)
uV1  =  218.3639**(J/gm)      (internal energy, satuarated vapor at 1 bar)
rhoL1  =  1.393**(gm/cm^3)      (density, saturated liquid at 1 bar)
rhoV1  =  0.005705**(gm/cm^3)      (density, saturated vapor at 1 bar)
```

2 bar

```
hV2  =  238.2252**(J/gm)      (enthalpy, saturated vapor at 2 bar)
```

3 bar

```
uL3  =  82.2382**(J/gm)      (internal energy, saturated liquid at 3 bar)
rhoL3  =  1.349**(gm/cm^3)      (density, saturated liquid at 3 bar)
```

(3.2) Calulate Boiloff

There is a fixed volume V of liquid argon at bar, Vapor is withdrawn until the pressure in the fixed volume is 1 bar. Assume the enthalpy of the vapor withdrawn is saturated vapor at 2 bar, the average pressure.

Calculate the volume fraction of vapor y, remaining in the volume V when the process is over. In the derivation the volume V cancels out.

```
y  =  0.0820121702
```

Find the initial and Total mass, assuming V = 1 cm^3.

Find the mass left inthe volume, when its pressure is 1 bar.

```
M1  =  (y*rhoV1+(1-y)*rhoL1)*1**(cm^3)
M1  =  1.2792249263**gm
```

Find the fraction of the original mass which boils off.

```
boiloff  =  (Mtotal-M1)/Mtotal      (fraction of liquid that boils off)
boiloff  =  0.0517235535
```

Therefore the internal energy of the liquid argon can only boiloff 5.1% of the liquid.